Banisteria, Number 37, pages 21-29

Timber Harvesting Effects on Small Terrestrial Vertebrates and Invertebrates on Grassy Hill Natural Area Preserve, Franklin County, Virginia

Caleb S. Burruss, Todd S. Fredericksen, and Glen Stevens

School of Natural Science and Mathematics
Ferrum College
Ferrum, Virginia 24088

ABSTRACT

We captured small terrestrial vertebrates and invertebrates using live traps at the Grassy Hill Natural Area Preserve near Rocky Mount, Virginia to compare their abundance and species composition in an area where a timber harvest was conducted to restore open woodland habitat for rare plant species with that of an adjacent unharvested forest tract. In general, we captured few species of vertebrates on the site, but large numbers of invertebrates were captured in pitfall traps. Amphibian captures were significantly higher on the unharvested tract, mostly due to larger numbers of juvenile American Toads (*Anaxyrus americanus*). Captures were also higher on the unharvested site for most invertebrate orders. Small mammal captures also tended to be higher in the unharvested tract, but not significantly. Reptile captures were similar for the harvested and unharvested tracts. In the short-term, most groups of vertebrate and invertebrate animals had lower captures on the harvested site compared to the unharvested control site.

Key words: Timber harvesting, amphibians, small mammals, reptiles, invertebrates.

INTRODUCTION

Timber harvesting is typically conducted to obtain wood products, but can also be used as a tool for ecological restoration (Elliott & Hewitt, 1997; Fuller et al., 2004). The Virginia Department of Conservation and Recreation (DCR) is currently using single tree selection timber harvesting to restore open woodland communities on the Grassy Hill Natural Area Preserve in Franklin County, Virginia. A combination of dry, mafic soils along with fire as a natural and anthropogenic disturbance agent resulted in the formation of grass-dominated plant communities along with scattered trees, predominantly oak species (*Quercus* spp.) (DCR 2010). With the suppression of fire, most of Grassy Hill has been converted to closed forest, reducing habitat for some rare plant species, including the federally endangered Smooth Coneflower (*Echinacea laevigata*). DCR is currently using timber harvesting to open the forest canopy on the preserve along with prescribed fire to restore open woodland communities.

Timber harvesting affects wildlife populations by modifying habitat conditions. DCR is interested in understanding how the restoration treatments will affect species of small vertebrates and invertebrates. Small vertebrate populations represent an important biotic component in forests because of their abundance and role in community and ecosystem processes. For example, they serve as a prey base for larger animals and may also be important predators of invertebrates (Buckner, 1966; Burton & Likens, 1975; Sullivan, 1990). Small mammals are also important dispersers of seeds and fungal spores and play an important role in the turnover of organic matter (Stoddart, 1979). Many amphibian species are sensitive to environmental changes and are useful for monitoring ecosystem integrity (Welsh & Droege, 2001). Invertebrates also play important roles in forest ecosystems, serving as detritivores, herbivores, pollinators, predators, and prey items (Rosenberg et al., 1984; Wilson, 1987), but much less is known about them than vertebrates, particularly their response to timber harvesting.

We tested the hypothesis that timber harvesting of mature forest would affect the abundance, species composition, and species diversity of small vertebrate communities compared to an untreated forest on the Grassy Hill Natural Area Preserve in Franklin County,

Virginia. This information should help DCR determine the effects of this habitat management technique on small vertebrate communities. A prescribed burn was also planned for the timber harvested area prior to our study, but it was not conducted due to logistical issues and unfavorable weather conditions.

METHODS

Site Description

Grassy Hill Natural Area Preserve is located in Franklin County, Virginia, just west of the town of Rocky Mount. The Preserve was created in 1992 with the support of The Nature Conservancy and is managed by the Virginia Department of Conservation and Recreation. The Preserve includes approximately 1,440 acres and contains forests dominated by oak and hickory, Piedmont basic woodlands, and small remnants of Piedmont prairie. Soils are shallow, basic, and clayey and are derived from magnesium-rich bedrock.

The study area was within Unit 1 of the Preserve located on the western edge of Rocky Mount, on the lower eastern slopes of Grassy Hill, at about 400 m in elevation (Fig. 1). A 55-acre tract within this unit was harvested in the spring of 2009. The goal of this harvest was to accelerate restoration and expansion of open woodland and Piedmont prairie communities, portions of which are probable Smooth Coneflower (*Echinacea laevigata*) habitat. The combination of timber harvesting followed by prescribed burning would alter forest structure and species composition to a condition that would resemble that of forests on this site when they were under the regular influence of fire. The subsequent reduction in forest floor litter and duff, coupled with increased solar radiation on the forest floor, is expected to stimulate seed germination and grass/forb production.

We conducted a systematic sample of the density and basal area of tree species within the harvested tract and an adjacent unharvested tract after harvesting in September 2009. From a random starting point near one corner of the harvested area, we located ten 0.4 ha circular plots in a grid with each point separated by 50 m. All live trees >10 cm diameter-at-breast height were measured. Similarly, we sampled the adjacent unharvested tract. The harvested tract had approximately one-half the basal area and one-third of the tree density as the unharvested tract (Table 1). White Oak (*Quercus alba*) had the highest density and basal area in each tract and the species occurring in each tract were generally similar, although the proportions differed (Table 1). Most notably, Post Oak (*Quercus stellata*) was the second most abundant species on the harvested tract and had twice the density there compared to the unharvested tract. There were some topographic differences between the harvested and unharvested areas. The border of the two tracts met on a side slope with the unharvested area towards the upper slope, continuing over a low ridge to the other side down to a toe slope position (Fig. 1).

Sampling

From June-September 2010, we sampled small vertebrates and invertebrates within adjacent harvested and unharvested areas. Two different sampling methods were employed with equal effort among the two treated areas including live trapping for small mammals and pitfall trapping for small mammals, reptiles, amphibians, and invertebrates. Trapping was conducted under the specifications set by the Virginia Department of Game and Inland Fisheries scientific collection permit #38636 granted to Todd Fredericksen. All sampling was conducted at least 50 m from treatment borders to minimize edge effects.

We conducted pitfall trapping using a drift fence-pitfall trap design that has been highly successful in capturing small vertebrates at a nearby location (Fredericksen et al., 2010). In each treatment, three drift fence-pitfall arrays were established with each array in a treatment located at least 50 m apart. Each array was in the shape of a "+". At the center of each array, a 20 l plastic bucket was buried flush with the ground level. Woven plastic silt fence supported by wooded stakes was then placed in the four cardinal directions 5 m out from the central bucket with the bottom of the fence buried in the ground. At the terminus of each drift fence segment, another bucket was installed in the ground. The lid of each bucket was supported by wooden stakes approximately 25 cm above the bucket to reduce rainfall entry and provide shade for captured animals. Holes were drilled in the bottom of the buckets to facilitate water drainage. Traps were installed in early June and checked daily, except for some weekends and holidays when the traps were closed if no one was available to check them. The total number of trap-nights per treatment equaled 540 (15 buckets x 36 nights opened). Every morning, the number of captured vertebrates per species was recorded for each trap and animals were released just outside of and facing away from the pitfall trapping area. Released animals were not marked. Invertebrate species were similarly counted at the order level and then released outside of the trapping area.

Live trapping for mammals was also conducted using Sherman live traps. Twenty-five 30 x 9 cm

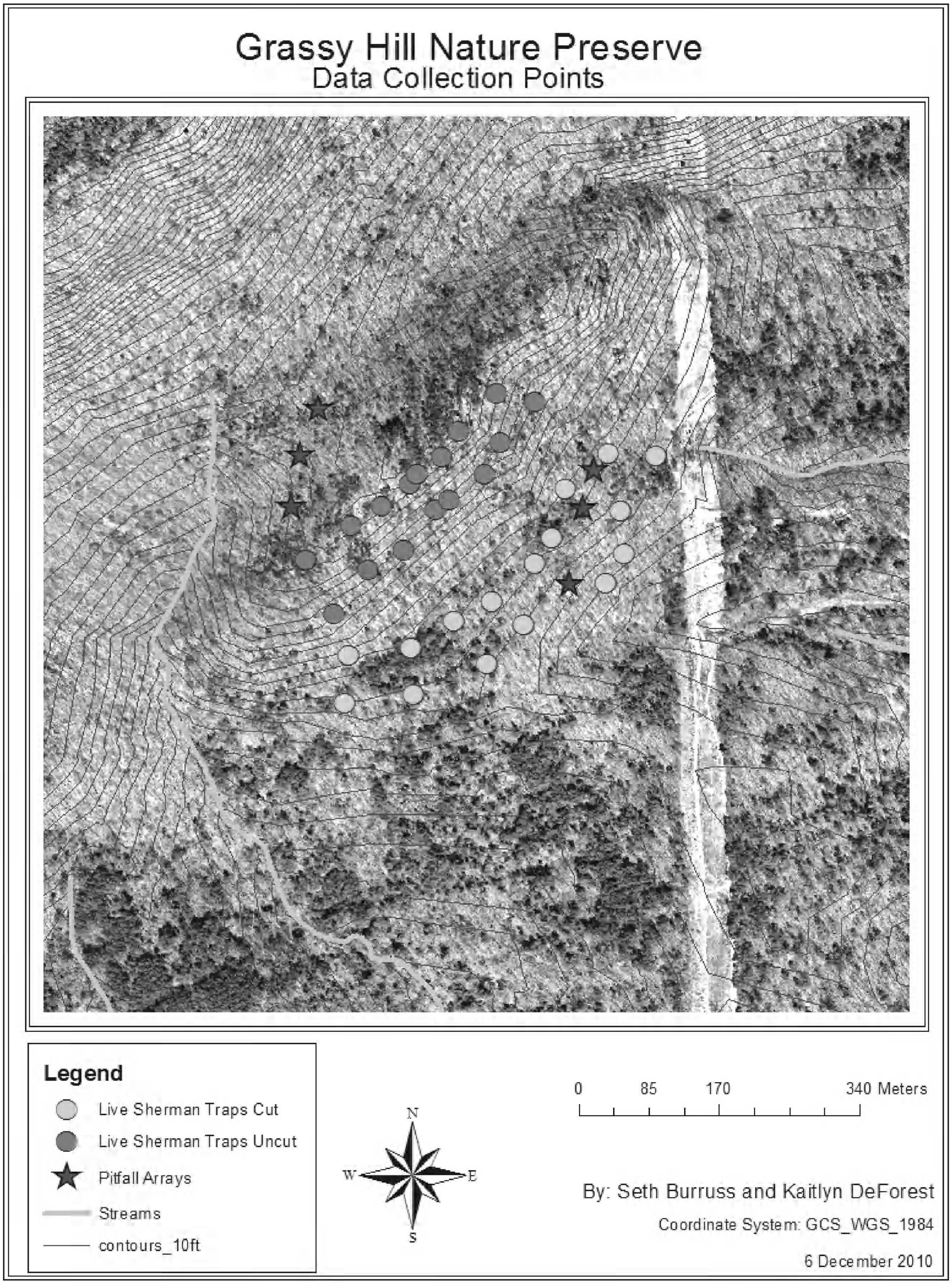

Fig. 1. Map of Grassy Hill Natural Area Preserve study area and sampling locations.

Table 1. Density and basal area of trees > 10 cm diameter-at-breast height in harvested and unharvested areas of Grassy Hill Natural Area Preserve based on ten 0.4 ha circular plots in each area.

Harvested Area

Common name	Species name	Density (trees/ha)	Basal area (m^2/ha)
White Oak	*Quercus alba*	53.8	5.40
Post Oak	*Quercus stellata*	43.7	1.82
Pignut Hickory	*Carya glabra*	19.3	0.92
Black Oak	*Quercus velutina*	4.1	0.22
Blackjack Oak	*Quercus marylandica*	3.0	0.21
Sourwood	*Oxydendrum arboreum*	2.0	0.01
Blackgum	*Nyssa sylvatica*	1.0	0.02
Virginia Pine	*Pinus virginiana*	1.0	0.05
Cucumbertree	*Magnolia acuminata*	1.0	0.02
Shortleaf Pine	*Pinus echinata*	1.0	0.18
TOTAL		**129.9**	**8.85**

Unharvested Area

Common name	Species name	Density (trees/ha)	Basal area (m^2/ha)
White Oak	*Quercus alba*	163.3	10.18
Pignut Hickory	*Carya glabra*	61.6	1.13
Virginia Pine	*Pinus virginiana*	59.3	3.69
Post Oak	*Quercus stellata*	23.3	0.72
Red Maple	*Acer rubrum*	23.3	0.44
Chestnut Oak	*Quercus montana*	12.7	0.44
Mockernut Hickory	*Quercus alba*	8.5	0.25
Tuliptree	*Liriodendron tulipifera*	8.5	1.44
Blackgum	*Nyssa sylvatica*	6.4	0.27
Blackjack Oak	*Quercus marylandica*	6.4	0.21
Black Oak	*Quercus velutina*	2.1	0.06
TOTAL		**375.4**	**18.83**

Table 2. Amphibian captures for three pitfall arrays in harvested and unharvested tracts from June-September 2010 on Grassy Hill Natural Area Preserve, Rocky Mount, Virginia.

Species	Harvested	Unharvested
American Toad (*Anaxyrus americanus*)	67	108
Wood Frog (*Lithobates sylvaticus*)	1	3
TOTAL	**68**	**111**

aluminum traps were set out in a grid within each treatment area. The grid consisted of eight sites located 25 m apart with each site having three or four traps baited with peanut butter and oatmeal. Trapping occurred simultaneously in all treatments for four consecutive days during nine weeks from June-August for 900 trap-nights (36 nights x 25 traps). Mammals were ear-tagged and released.

Data Analysis

When there was a sufficient number of captures to compare, we used a chi-square analysis to test for differences in captures between the harvested and unharvested tracts for individual species or species groups. Statistical analyses were performed using SYSTAT 12.2 (SYSTAT Software, Inc., San Jose, CA).

RESULTS

A total of 2,441 captures of vertebrates and invertebrates was recorded over the four-month period, including 45 mammals, 179 amphibians, and 20 reptiles. The majority of captures were invertebrates (n = 2197). Overall, we found higher numbers of both vertebrates and invertebrates in the unharvested tract. Capture rates tended to be higher following rainfall events for all taxonomic groups.

Amphibians represented 73% of the vertebrate captures, nearly all of which were metamorphs or otherwise juvenile American Toads (*Anaxyrus americanus*) (Table 2). The only other amphibian species captured was the Wood Frog (*Lithobates sylvaticus*). Of the 179 amphibians captured, 111 were recorded in the unharvested forest stand compared to 68 in the harvested stand (χ^2=5.23, p = 0.02) (Table 2).

Mammals represented 18% of total vertebrate captures and consisted primarily of White-footed Mice (*Peromyscus leucopus*) (54%) and shrews (Soricidae) (44%). Excluding recaptures, seven White-footed Mice were captured in the harvested stand and 17 in the unharvested stand, all but one of which were taken in Sherman traps (χ^2=2.17, p = 0.14). Shrews were also captured more often in the unharvested compared to the harvested tract (14 vs. 6) (χ^2=1.67, p = 0.20) (Table 3).

Reptiles comprised 9% of the total vertebrate captures, the most numerous of which was the Eastern Fence-Lizard (*Sceloporus undulatus*), which made up 60% of all reptiles captured (Table 4). There was a similar number of captures of this species in both harvested and unharvested tracts. The Common Five-lined Skink (*Plestiodon fasciatus*) represented 25% of the reptile captures and had four times more captures in the unharvested stand than in the harvested stand. Smooth Earthsnake (*Virginia valeriae*) and Wormsnake (*Carphophis amoenus*) were also captured in lower numbers with relatively even distribution among the two tracts.

Invertebrates of nine orders were captured in the pitfalls arrays (Table 5) with nearly double the number of captures in the unharvested tract compared to the harvested one (χ^2=95.50, p<0.001). Beetles (Coleoptera) accounted for 40% of the invertebrate captures, with significantly higher numbers in the unharvested tract (χ^2=4.10, p = 0.04). Spiders (Araneae) were the second most abundant invertebrate order, comprising 23% of the captures, with significantly higher numbers in the unharvested tract (χ^2=10.03, p = 0.002). The remaining invertebrate orders in decreasing capture frequencies were: Orthoptera 17% (crickets), Spirobolida 8% (millipedes), Blattodea 7% (roaches), Lepidoptera 3% (larvae of moths and butterflies), Heteroptera 1% (true bugs), Geophilomorpha 0.8 % (centipede), and Polydesmida 0.7% (flat millipede). All of these orders except Lepidoptera had significantly (p<0.05) more captures on the unharvested tract, whereas Lepidoptera larvae were captured significantly more often on the harvested tract (χ^2=10.12, p = 0.001).

DISCUSSION

Timber harvesting, especially intensive harvesting such as clearcutting, dramatically changes environmental conditions, species composition, and vegetative structure within forests (Chen et al., 1999; Zheng et al., 2000). Not all species, however, are negatively affected by these changes. Wildlife species react differently to the variety of habitat modifications caused by timber harvesting, including decreased overstory cover, increased ground vegetation cover, increased downed coarse woody debris, and changes in the abundance of food resources (DeCalesta, 1989; Healy, 1989). For example, on privately-owned woodlots in Virginia, timber harvesting significantly increased the abundance and species richness of small mammals and reptiles (Fredericksen et al., 2006; Shively et al., 2006), but resulted in a decrease in the abundance of some salamander species (Fredericksen et al., 2006).

In this study, we captured more small terrestrial vertebrates and invertebrates in the unharvested tract than the harvested forest, although the differences were not statistically significant for all groups. This result differs from those of other studies of timber harvesting conducted in Franklin County (Fredericksen et al., 2006; Shively et al., 2006) where small mammals and reptiles tended to be more abundant on harvested sites compared to unharvested ones, while captures of

Table 3. Mammal captures for three pitfall arrays in harvested and unharvested tracts from June-September 2010 on Grassy Hill Natural Area Preserve, Rocky Mount, Virginia.

Species	Harvested	Unharvested
Masked Shrew (*Sorex cinereus*)	3	9
Smokey Shrew (*Sorex fumeus*)	3	5
Red-backed Vole (*Myodes gapperi*)	1	0
TOTAL	**7**	**14**

Table 4. Reptile captures for three pitfall arrays in harvested and unharvested tracts from June-September 2010 on Grassy Hill Natural Area Preserve, Rocky Mount, Virginia.

Species	Harvested	Unharvested
Eastern Fence-Lizard (*Sceloporus undulatus*)	6	6
Common Five-Lined Skink (*Plestiodon fasciatus*)	1	4
Smooth Earthsnake (*Virginia valeriae*)	1	0
Wormsnake (*Carphophis amoenus*)	1	1
TOTAL	**9**	**11**

Table 5. Invertebrate captures by order for three pitfall arrays in harvested and unharvested tracts from June-September 2010 on Grassy Hill Natural Area Preserve, Rocky Mount, Virginia.

Taxonomic Group (Order)	Harvested	Unharvested
Geophilomorpha (Centipedes)	5	14
Spirobolida (Millipedes)	31	138
Polydesmida (Millipedes)	3	15
Araneae (Spiders)	206	307
Heteroptera (True bugs)	4	25
Coleoptera (Beetles)	399	484
Orthoptera (Crickets)	70	315
Blattodea (Roaches)	30	116
Lepidoptera (Moth and butterfly larvae)	30	5
TOTAL	**788**	**1419**

amphibians tended to be similar. This study is limited in that it occurred only on one site with pseudoreplicated data and examined the effects of harvesting after only one year. Further sampling may be conducted at this site in future years in order to determine longer-term effects. This study may also serve as a baseline for determining the effects of prescribed fire to these stands, if this treatment is implemented at this site.

The large number of juvenile toads captured on the study site may be due to the dispersal of these animals during this time of year from breeding locations somewhere on or near Grassy Hill. While toads have been shown to tolerate the desiccating conditions in harvested areas better than other amphibians (Rittenhouse et al., 2008), it has been observed that migrating juvenile amphibians generally avoid areas without canopy cover (Patrick et al., 2006; Semlitsch et al., 2008). In addition, although it is uncertain where the natal habitat of the juvenile toads was located, the unharvested tract is closer to a permanent drainage than the harvested one, suggesting that captures were more likely in the former area. Wood Frogs prefer to breed in vernal pools in closed forests (Skelly et al., 2002), which may explain the higher number of captures in the unharvested tract.

Small mammals had higher capture rates in the unharvested stand, consisting mostly of White-footed Mice and shrews. These results contrast with those of Shively et al. (2006), who found a three-fold greater abundance of small mammals on timber-harvested sites compared to unharvested sites in Franklin County. The higher capture rate of shrews on unharvested areas in our study may be due to the higher moisture requirements of these species (Kirkland, 1990). Several studies have observed, however, that shrew populations are not affected greatly by changes in forest overstory cover (Ford & Rodrigue, 2001; Greenberg & Miller, 2004; Matthews et al., 2009), although Greenberg et al. (2007) found that high intensity disturbance to the forest canopy can negatively affect shrews. Part of the unharvested tract appeared to have more exposed rock crevices, which perhaps supported more cover habitat to support larger small mammal populations. The dry, exposed location of Grassy Hill may also make harvested locations less suitable than those on moister sites.

Reptiles are more adapted to higher temperatures and lower moisture levels that are characteristic of harvested tracts. However, reptile captures were similar on harvested and unharvested tracts and more Common Five-lined Skinks were found on the unharvested tract. In selectively-logged hardwood forests, Ross et al. (2000) and Fredericksen et al. (2006) found a higher abundance of snakes and lizards in logged stands compared to unlogged hardwood stands, attributing this to the greater availability of areas for basking and greater quantities of downed coarse woody debris. Food availability for small snakes and lizards, however, appeared to be higher in the unharvested tract at Grassy Hill given the larger number of captures of invertebrates there compared to the harvested tract.

With the exception of Lepidoptera, all orders of invertebrates had higher captures in the unharvested tract. Time since logging may be a factor explaining the higher invertebrate species observed on the unharvested tract in this study. Species of invertebrates vary widely with respect to habitat requirements, ranging from open environments, such as those associated with logging, and closed canopy forest conditions (Werner & Raffa, 2000; Pearce & Venier, 2006). Following logging, species composition gradually changes from a dominance of forest species to open habitat species (Niemelä et al., 1993; Pearce & Venier, 2006). Immediately after logging, forest species are likely to be in decline, but open habitat species are perhaps only beginning to colonize the harvested tract. In addition, habitat structural features that may be enhanced by logging may take time to become suitable for invertebrates. For example, logging in hardwood forests generally increases the amount of coarse woody debris on the forest floor (Shively et al., 2006), which was the case for the harvested tract in this study. Until it decays, however, it may not be useful for overwintering or oviposition sites for many species of invertebrates (Pearce & Venier, 2006). Similarly, studies have shown that invertebrates often have a higher abundance in grassy openings compared to adjacent closed forests due to increased amounts of herbaceous cover (Martin & McGinnes, 1975; Healy, 1985). The herbaceous vegetation on the harvested tract was still in the process of becoming established, as evidenced by a significant amount of bare soil present on this site. As vegetation establishment continues, invertebrate populations are likely to increase. With continued monitoring of these sites in future years and further detailed taxonomic discrimination, we hope to understand longer-term impacts of harvesting on invertebrate abundance and species composition at Grassy Hill.

ACKNOWLEDGMENTS

Special thanks to The Appalachian College Association for funding provided to Seth Burruss and to Bryan Wender of the Virginia Department of Conservation and Recreation. Thanks to Mavrik Mann who helped install the drift fence arrays and check traps and to Brad Robertson and Kaitlyn DeForest who helped check pitfall traps. We thank Claiborne Woodall

for reviewing an earlier draft of this manuscript.

LITERATURE CITED

Buckner, C. H. 1966. The role of vertebrate predators in the biological control of forest insects. Annual Review of Entomology 11: 836-845.

Burton, T. M., & G. E. Likens. 1975. Energy flow and nutrient cycling in salamander populations in the Hubbard Brook Experimental Forest, New Hampshire. Ecology 56: 1068-1080.

Chen, J., C. Saunders, T. R. Chow, R. J. Naiman, K. D. Brosofske, G. D. Mroz, B. L. Brookshire, & J. F. Franklin. 1999. Microclimate in forest ecosystems and landscape ecology. BioScience 49: 288-297.

DeCalesta, D. S. 1989. Even-aged forest management and wildlife populations. Pp. 210-224 *In* J. C. Finley & M. C. Brittingham (eds.), Timber Management and Wildlife Populations. Pennsylvania State University, University Park, PA.

DCR. 2010. Virginia Department of Conservation and Recreation. http://www.dcr.virginia.gov/natural_heritage/natural_area_preserves/grassyhill.shtml

Elliot, K. J., & D. Hewitt. 1997. Forest species diversity in upper elevation hardwood forests in the southern Appalachian Mountains. Castanea 62: 32-42.

Ford, W. M., & J. L. Rodrigue. 2001. Soricid abundance in partial overstory removal harvests and riparian areas in an industrial forest landscape in the central Appalachians. Forest Ecology and Management 152: 159-168.

Fredericksen, T. S., J. D. Fiore, H. S. Shively, M. B. Webb, J. L. Scott, & R. L. Smith. 2010. Activity patterns of small terrestrial vertebrates and relationship to coarse woody debris in Virginia Piedmont forests. Banisteria 35: 53-60.

Fredericksen, T. S., K. Graves, & T. Pohlad-Thomas. 2006. Herpetofauna in logged and unlogged forest stands in south-central Virginia. Catesbeiana 26: 52-63.

Fuller, A. K., D. J. Harrison, & H. J. Lachowski. 2004. Stand scale effects of partial harvesting and clearcutting on small mammals and forest structure. Forest Ecology and Management 191: 373-386.

Greenberg, C. H. & S. Miller. 2004. Soricid response to canopy gaps created by wind disturbance in the Southern Appalachians. Southeastern Naturalist 3: 715-732.

Greenberg, C. H., S. Miller, & T. A. Waldrop. 2007. Short-term response of shrews to prescribed fire and mechanical fuel reduction in a southern Appalachian upland hardwood forest. Forest Ecology and Management 243: 231-236.

Healy, W. M. 1985. Turkey poult feeding activity, invertebrate abundance, and vegetation structure. Journal of Wildlife Management 49: 466-472.

Healy, W. M. 1989. Uneven-aged silviculture and wildlife habitat. Pp. 225-237 *In* J. C. Finley & M. C. Brittingham (eds.), Timber Management and Wildlife Populations. Pennsylvania State University, University Park, PA.

Kirkland, G. L., Jr. 1990. Patterns of initial small mammal community change after clearcutting of temperate North American forests. Oikos 59: 313-320.

Martin, D. D., & B. S. McGinnes. 1975. Insect availability and use by turkeys in forest clearings. Proceedings of the National Wild Turkey Symposium 3: 70-75.

Matthews, C. E., C. E. Moorman, C. H. Greenberg, & T. A. Waldrop. 2009. Response of soricid populations to repeated fire and fuel reduction treatments in the southern Appalachian Mountains. Forest Ecology and Management 257: 1939-1944.

Niemelä, J., D. Langor, & J. R. Spence. 1993. Effects of clear-cut harvesting on boreal ground-dwelling beetle assemblages (Coleoptera: Carabidae) in western Canada. Conservation Biology 7: 551-561.

Patrick, D. A., M. L. Hunter, & A. J. K. Calhoun. 2006. Effects of experimental forestry treatments on a Maine amphibian community. Forest Ecology and Management 234: 323-332.

Pearce, J. L., & L. A. Venier. 2006. The use of ground beetles (Coleoptera: Carabidae) and spiders (Araneae) as bioindicators of sustainable forest management: A review. Ecological Indicators 6: 780-793.

Rittenhouse, T. A. G., E. B. Harper, L. R. Rehard, & R. D. Semlitsch. 2008. The role of microhabitats in the desiccation and survival of anurans in recently harvested oak-hickory forest. Copeia 2008: 807-814.

Rosenberg, D. M., H. V. Danks, & D. M. Lehmkuhl. 1986. Importance of insects in environmental impact assessment. Environmental Management 10: 773-783.

Ross, B. R., T. S. Fredericksen, E. Ross, W. Hoffman, M. B. Lester, J. Beyea, B. N. Johnson, M. Morrison, & N. J. Fredericksen. 2000. Herpetofauna abundance and species richness on recently-harvested forest stands in Pennsylvania. Forest Science 46: 139-146.

Semlitsch, R. D., C. A. Conner, D. L. Hocking, T. A. G. Rittenhouse, & E. B. Harper. 2008. Effects of timber harvesting on amphibian persistence: testing the evacuation hypothesis. Ecological Applications 18: 283-289.

Shively, H. S., J. D. Fiore, & T. S. Fredericksen. 2006. The effects of timber harvesting on the abundance and diversity of small mammals on non-industrial private forestlands in southcentral Virginia. Banisteria 27: 31-36.

Skelly, D. K., L. K. Freidenburg, & J. M. Kiesecker. 2002. Forest canopy and the performance of larval amphibians. Ecology 83: 983-992.

Stoddart, D. M. 1979. Ecology of Small Mammals. Chapman and Hall, New York. 386 pp.

Sullivan, T. P. 1990. Demographic responses of small mammal populations to herbicide application in coastal coniferous forest: population density and residency. Canadian Journal of Zoology 68: 874-883.

Welsh, H. H., Jr., & S. Droege. 2001. A case of using plethodontid salamanders for monitoring biodiversity and ecosystem integrity of North American forests. Conservation Biology 15: 558-569.

Werner, S. M., & K. F. Raffa. 2000. Effects of forest management practices on the diversity of ground-occurring beetles in mixed northern hardwood forests of the Great Lakes region. Forest Ecology and Management 139: 135-155.

Wilson, E. O. 1987. The little things that run the world. Conservation Biology 1: 344-346.

Zheng, D., J. Chen, B. Song, M. Xu, P. Sneed, & R. Jensen. 2000. Effects of silvicultural treatments on summer forest microclimate in southeastern Missouri Ozarks. Climate Research 15: 45-49.